

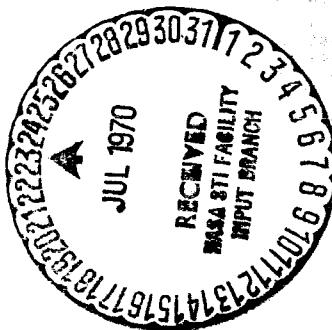
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TECHNICAL MEMORANDUM

SPACE TRANSPORTATION SYSTEM ANALYSIS

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ABSTRACT

An analysis of the space transportation system candidates for the 70's and 80's has been started, based on the premise that the space shuttle must be viewed as part of the total transportation system, rather than an isolated element. The intent was to re-examine the current commitment to an all-up development of a two stage fully recoverable lifting body shuttle. This document is a status report for the study and presents some conclusions based on results from early portions of the study. The final study results will be documented later.

The report is given here as a status briefing, using view-graphs and associated text.

Results indicate that many shuttle configuration concepts have yet to be explored, and many of these promise advantages of one kind or another over the current shuttle configuration. In addition, treating the shuttle as part of the total transportation system has far-reaching effects. Principal among these is the strong indication that evolutionary shuttle development is, in many cases a graceful and flexible approach to the shuttle program.

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Abstract Only

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**SPACE TRANSPORTATION
SYSTEM
ANALYSIS**

INTRODUCTION

This is a status report on an investigation of the configuration alternatives for the space shuttle for the late 70's and 80's. The approach to this issue is founded on the premise that a space shuttle must be a part of the total space transportation system of the 80's.

The Configuration options are assumed to be unconstrained. Consequently, the investigation will begin with a statement of the basic transportation requirements, and from these will derive a basic set of configuration variables. The possible combinations of these variables will be defined in the form of a set of configuration concepts. These will then be screened to produce a reasonably small group which can be evaluated and compared against the current shuttle concept in more detail.

Although the results are not yet finalized, some interesting conclusions and observations may be drawn about the spectrum of attractive potential shuttle configurations, and about the utility of an evolutionary shuttle development program.

INTRODUCTION

GROUND RULE

- THE SHUTTLE IS PART OF A TRANSPORTATION SYSTEM

ANALYSIS STRUCTURE

- SYSTEM REQUIREMENTS
- ALTERNATIVES
- EVALUATION

ISSUES

- CURRENT PROGRAM COMMITMENTS
- EVOLUTIONARY PROGRAMS

TRANSPORTATION SYSTEM REQUIREMENTS

There are three basic transportation system requirements, two are functional jobs, and the third is an economic restriction.

The first job is to provide round trip transportation for space station logistics and independent shuttle missions. This has directly associated with it some small cargo; about 10,000 to 25,000 pounds being sufficient based on preliminary results from the current space station studies. For large crew rotation missions the cargo could consist of 10 to 12 people. Low acceleration is required on both the ascent and descent flights.

The second major job is the lifting of fairly large payloads. These are comprised primarily of either bulk cargo, or large individual modules such as space stations, Mars Excursion Modules, or nuclear stages. These are all typically ascent only payloads. Based on current estimates, a 50,000 to 150,000 lb capacity would be adequate to handle all future large payloads.

The economic restriction is simply that the system be considerably cheaper than the current Saturn V. A factor of 4 on the cost per pound should permit the transportation system to pay for its own development in 8 to 10 years. However, most commercial endeavors hesitate to embark on a major new development unless the promise of an order of magnitude savings exists. These two savings factors apply to the total transportation job, and have no direct correspondence to the high and low payload transportation requirements.

NASA/MSF TRANSPORTATION
SYSTEM REQUIREMENTS

- PROVIDE CREW TRANSPORTATION
 - 2 PEOPLE, AND 10KLB TO 25KLB PAYLOAD
 - 12 PEOPLE
 - LOW ACCELERATION
 - ROUND TRIP
- PROVIDE LARGE CARGO TRANSPORTATION
 - 150,000 LB. TO LOW EARTH ORBIT
 - PROPELLANTS
 - UP PAYLOAD ONLY
- BE CHEAPER PER POUND OF PAYLOAD THAN SAT.V
 - FACTOR OF 4 INITIALLY
 - FACTOR OF AT LEAST 10 ULTIMATELY

SYSTEM VARIABLES

The three basic transportation requirements must be interpreted in terms of a series of major configuration variables. This process is by no means straight forward, and the actual analysis required many iterative cycles before the set of variables and relationships shown here evolved. The first attempts included numerous other factors, and long and careful consideration was required to distill this minimum set of variables from the initial list.

The requirement to transport the crew implicitly demands a recoverable crew vehicle. Here two major configuration variables seem to exist. One is the nature of the interface between the booster and the crew systems. The current shuttle concepts have the crew systems integrated into the booster upper stage. It is technically feasible, however, to have a non-propulsive crew vehicle that is delivered to orbit by the booster. The second crew system variable is the aerodynamic recovery mode, and by this we mean the aerodynamic shape. These fall into two general classes -- lifting or winged bodies and ballistic bodies. The principal difference here is that the ballistic shape is more amenable to efficient propulsive tankage while the lifting bodies are more amenable to efficient flying.

The requirement for economical operation leads to the consideration of fully recoverable and partially recoverable systems in competition with expendable systems. The extent of expendability is certainly a major configurational variable. And since recovery is one potential way of improving the economic picture, the recovery mode is a variable in exactly the same way that it was with the crew systems, namely in the aerodynamic shape.

The third requirement, a large lifting capacity, can often be obtained by adding stages or tankage to an existing booster system. The staging characteristics of the system are thus a major configuration variable growing out of the need to lift large payloads. In all of these discussions, the round trip payload is assumed to be carried internally along with the crew, while the large payload is assumed to be carried externally.

SYSTEM VARIABLES

REQUIREMENTS	CONFIGURATION VARIABLES
TRANSPORT CREW	BOOSTER INTERFACE RECOVERY MODE
ECONOMICAL OPERATION	EXPENDABILITY RECOVERY MODE
LARGE LIFTING CAPACITY	STAGING

REQUIREMENTS	CONFIGURATION VARIABLES
TRANSPORT CREW	BOOSTER INTERFACE RECOVERY MODE
ECONOMICAL OPERATION	EXPENDABILITY RECOVERY MODE
LARGE LIFTING CAPACITY	STAGING

VEHICLE VARIABLES

A typical transportation system must consist of a crew vehicle and a booster, although these two systems do not always have to be separate entities. Looking at the transportation system this way allows the system variables identified previously to be associated with the major hardware elements.

Booster

Both horizontal vertical takeoff modes are possible, however, the large size and facility investments associated with horizontal takeoff systems has caused them to be dropped from past recoverable system studies, and so they are not considered here.

Both one and two stage booster systems are considered at this stage of the analysis. And the complete spectrum of recoverability must also be considered, ranging from expendable through half staging to fully recoverable.

Crew Vehicle

The crew vehicle may be integrated into one of the launch vehicle stages, and so participate in the boost propulsion, or it may be a separate vehicle whose prime propulsive function is to provide on-orbit and recovery propulsion. When integrated into the launch vehicle, the recovery mode is dictated by launch vehicle recovery, but as a separate vehicle it may be configured as either a lifting or a ballistic body.

VEHICLE VARIABLES

BOOSTER

TAKEOFf—

- 1) HORIZONTAL *
- 2) VERTICAL

STAGING—

- 1) ONE
- 2) TWO

RECOVERY —

- 1) EXPENDABLE
- 2) $\frac{1}{2}$ STAGING
- 3) FULL RECOVERY

RECOVERY MODE

- 1) BALLISTIC
- 2) LIFTING

CREW VEHICLE

BOOSTER INTERFACE—

- 1) INTEGRATED
- 2) SEPARATE

RECOVERY MODE

- 1) BALLISTIC
- 2) LIFTING

*—NOT CONSIDERED

CONFIGURATION VARIABLES

A transportation system with the maximum number of elements would consist of a two stage booster system and a separate crew vehicle. Combining this thought with the vehicle variables identified previously, yields the complete spectrum of configuration variables.

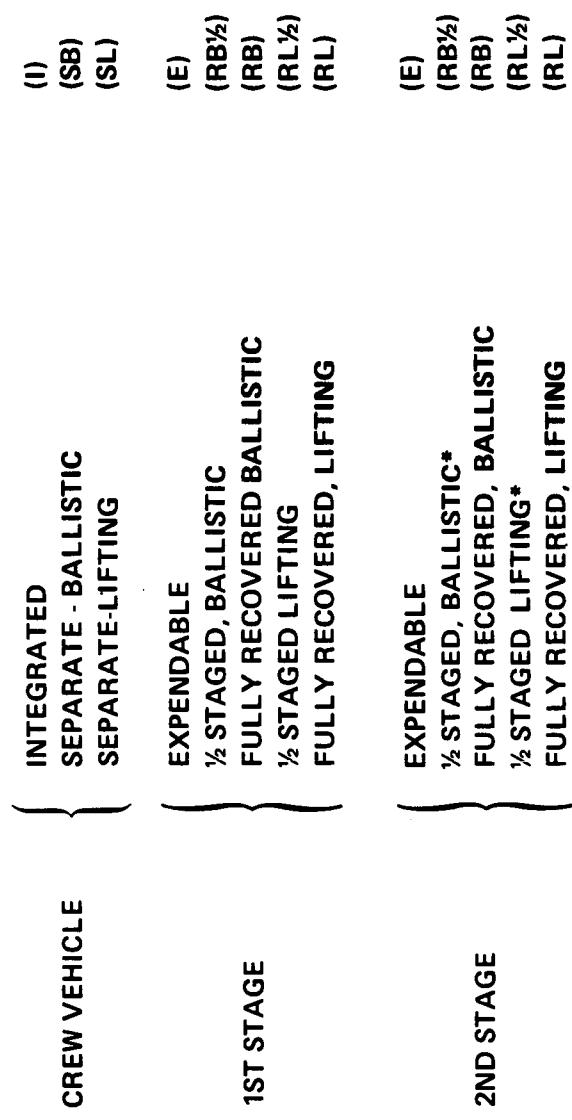
The crew vehicle has three options, one being integrated where the recovery mode is defined by the host vehicle, and the other two being separate crew vehicles, one for each recovery mode.

Both the first and second stage configuration variables cover the range of possible expendability states and recovery modes.

Adding tip tanks to the upper stages will generally result in these bulky systems being carried well through the period of maximum drag losses. In addition the total vehicle structure must be strong enough to carry the tip tank weight and the large lateral areas will increase wind induced loads. These facts tend to discourage the use of tip tanks on booster upper stages. Tip tanks on upper stages will not be considered in the rest of this analysis.

A configuration concept is specified by picking one of the configuration variables for each hardware element. The resulting concept is not a configuration in the conventional sense, but rather a generic class of configurations. With the exception of those alternatives specifically excluded, this list of variables should embrace all the possible configuration alternatives. Notice that the current shuttle concepts consisting of an integrated crew vehicle with a fully recovered lifting body first stage, and a fully recovered lifting body second stage all fall into one configuration concept.

CONFIGURATION VARIABLES



***GENERALLY NOT REALISTIC**

ALTERNATIVE MATRIX

After eliminating 1/2 staging as a configuration variable for the second stage, there remains 3 variables for the crew vehicle, 5 for the first stage and 3 for the second stage. Putting these together in all possible combinations, including the possibility of single stage systems, produces 60 configuration concepts. Since no evaluation criteria have been used, some of these 60 concepts will be patently ridiculous. However, any configuration that could be of interest should correspond to one of these alternatives or configuration categories. For example the current shuttle concepts are embraced by alternative 19.

The three rows at the bottom of the matrix refer to the subsequent screening process and are only shown here for future reference.

ALTERNATIVE MATRIX

VEHICLE ALTERNATIVES

*BOTH STAGES MUST BE THE SAME

SCREENING PROCESS

In the final phases of this study we would like to investigate the candidate shuttle configurations in enough detail to permit the selection of promising configuration concepts. Clearly 60 is too many to analyze, so a screening process was established. Up to this point, no distinction has been made between the transportation system for large payloads, and that for crew/logistics payloads. In order to have an unambiguous screening criterion the initial screening process will critique all the concepts as potential crew/logistics vehicles only. The cargo requirements will be considered later.

The first level of screening was to eliminate those alternatives which had obvious feasibility problems. For example a single stage to orbit lifting body cannot achieve orbit because the attainable mass fractions are too low, i.e., the performance is not adequate. As another criteria, single stage to orbit vehicles should not be expendable because they are fairly sophisticated machines, and hence expensive.

The number of stage developments required by any concept is an indication of development costs and can be used to eliminate some configuration. As a reasonable, if somewhat arbitrary rule, all systems requiring more than three developments were eliminated. This particular ground rule could be important to the outcome since it is the basis for elimination of many concepts.

Applying these screening criteria left 37 concepts to be considered. As a final act, simply to get an initial group small enough to consider, the current shuttle requirements were applied. Of the 37 concepts only those with no expendable elements and no more than two developments were considered. This produced a group of 11 configuration concepts. The 26 that were not selected are not eliminated, but merely set aside for the moment. Subsequent portions of the study will draw from that pool of concepts.

Although this screening process has little impact on the qualitative results presented in this report it does set the stage for quantitative analyses to be conducted later. Caution is in order when selecting screening criteria since they may bias the final analytical results

SCREENING PROCESS

- USE CREW/LOGISTICS MISSION

STEP ONE

- REJECT CANDIDATES BECAUSE
 - A ● PERFORMANCE NOT ADEQUATE
 - B ● EXPENDABLE CREW SYSTEMS
 - C ● EXPENDABLE SINGLE STAGE TO ORBIT VEHICLES
 - D ● MORE THAN THREE DEVELOPMENTS
- RESULT
 - 37 REMAINING CANDIDATES
 - 23 REJECTED CANDIDATES

STEP TWO

- APPLY PRESENT SHUTTLE PROGRAM REQUIREMENTS
 - 1 ● NO EXPENDABLE ELEMENTS
 - 2 ● NO MORE THAN TWO DEVELOPMENTS

RESULTS

- 11 CANDIDATES MEET SHUTTLE PROGRAM REQUIREMENTS
- 26 CANDIDATES DO NOT MEET REQUIREMENTS.

ELEVEN CANDIDATES

The eleven crew/logistics concepts surviving the two screening steps are shown here in cartoon form, with the cartoon code shown on the right.

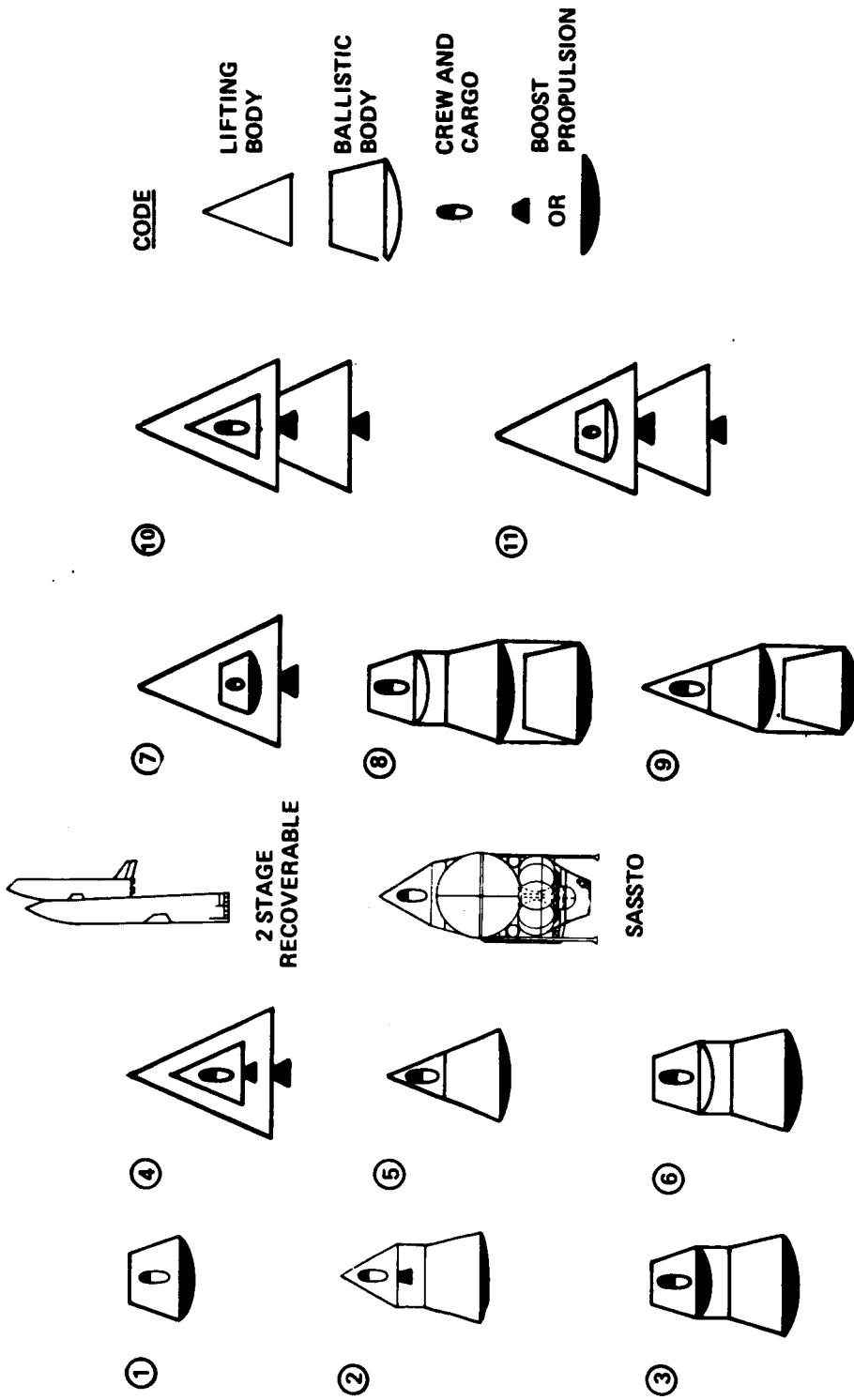
For example, concept 1 is a single stage to orbit ballistic booster, with the crew systems integrated into the booster.

Concept 4, which encompasses the current shuttle configurations consists of two lifting body stages, with the crew systems integrated into the upper stage.

Concept 2 may be visualized by replacing the shuttle lifting body first stage with a ballistic body first stage. In this concept the upper stage still provides a finite part of the boost velocity. Placing all the boost velocity requirement on the first stage of concept 2 yields concept 5 - a single stage to orbit ballistic booster with a separate lifting body crew vehicle.

In order to stay within the limit on the number of new developments, the two booster stages in concepts 8/9, and 10/11 must be of equal size.

ELEVEN CANDIDATES MEET
ALL REQUIREMENTS



VEHICLE SIZING

Using data taken from past contractor studies, the relationship between mass fraction and gross weights were established for lifting and ballistic vehicles.

The eleven candidate vehicles were sized for a 25,000 lb payload carried through ascent and descent. Sizes were also established for 1500 n.mi. crossrange, which affects the ballistic orbiter vehicles since this must be achieved propulsively. Lifting orbiters were not penalized for crossrange, although this is not strictly proper. Ballistic booster stages were required to deliver 1000 fps for landing whereas lifting vehicles were assumed to have all landing penalties included in the empty weight. Furthermore, ballistic vehicles that stage prior to attainment of orbit were required to either go on to orbit and then retro to land at the launch site or to execute a propulsive maneuver at separation to place on a return trajectory to the launch site. Lifting vehicles that separate prior to orbit insertion were assumed to be able to return to the launch site by aerodynamic flight means only. The weights shown were generated primarily to test the reasonableness of the various concepts, and to see if any major and consistent trends could be found.

As a general observation, all of the concepts show weights less than the Apollo Saturn V. Although it is desirable that gross launch weights be kept low, it is not clear at this time that minimum gross weight on the pad is valid as a principal criterion for selecting concepts.

About all that can be said is that none of the concepts, with the possible exception of concept 1, are patently infeasible. Concept 1 might be considered infeasible because of its general inability to affect crossrange either propulsively or aerodynamically, however the need for crossrange has not been clearly established. The concepts with lifting bodies as the crew vehicle have been assumed to have crossrange capability at no penalty. This is not precisely true but in any case the penalty for propulsive crossrange seems significant. This suggests that the need for crossrange must be definitely established before a shuttle decision is possible.

There is indication that ballistic vehicles may have advantages in spite of the propulsive velocity penalties required to compensate for the lack of aerodynamic lift. This arises because of the higher structural efficiencies of ballistic vehicles relative to lifting vehicles. This advantage is clear when no crossrange propulsion requirement (9000 fps) is imposed.

VEHICLE SIZING (IN 10^6 LBS.)

		VEHICLE SIZING (IN 10^6 LBS.)										
		1	2	3	4	5	6	7	8	9	10	11
NO	ORBITER	-	1,166	0.393	0.505	0.056	0.030	0.370	0.030	0.056	0.056	0.030
CROSS	BOOSTER	2,437	2,955	0.555	3,248	3,245	2,373	0.741	0.502*	0.704*	2,995*	2,716*
RANGE	ON-PAD	2,462	4,146	0.973	3,254	3,326	2,429	1,136	1,059	1,490	6,072	5,487
1500 NMI	ORBITER	-	SAME	0.899	SAME	SAME	0.089	0.543	0.089	SAME	SAME	0.089
CROSS	BOOSTER	N/A	1	2,742	1	1	4,393	2,417	0.959*	1	1	3,325*
RANGE	ON-PAD	-	4,146	3,684	3,254	3,326	4,507	2,985	2,031	1,490	6,072	6,764

PAYOUT = 25,000 UP AND DOWN

*BOTH BOOSTER STAGES

TRANSPORTATION SYSTEMS

Each of the eleven crew/logistics concepts must now be fitted into the total transportation system picture. The process is illustrated with concept 2.

Starting with concept 2 as a crew/logistics system, the first question to ask is: "what are the possible cargo derivatives for this concept?" Clearly one possibility is to oversize the lower stage so that it could lift, as a single stage to orbit system, about 150,000 pounds. Another possibility is to add expendable elements such as tip tanks or propulsive stages to the lower stage.

Once the possible cargo configurations have been identified, the feedback loop must be closed by asking: "if these are the cargo configurations, what alternative crew/logistics concepts might be derived from them?" Since the cargo versions can already lift 150,000 pounds to orbit, the crew/logistics derivative would most likely be the simple addition of a non propulsive crew vehicle to the large payload concept.

One final step is to examine the compatibility of this concept with an evolutionary development program. The most likely evolutionary approach is to develop the upper stage first, using expendable lower stages for flight tests and initial operations. Here there are two possibilities, depending on the size chosen for the orbiter stage. If it is small enough, it could be launched simply as a payload on a multi stage expendable system. If the orbiter is large, with appropriate propulsive capacity, it could be launched with an expendable lower stage. If the two stage expendable system is used, it might later serve, either temporarily or permanently, as the cargo configuration for the transportation system. Alternatively the lower stage could support the evolutionary development of the crew/logistics system with the full system providing the large lifting capacity.

The Transportation System synthesis described here, has been done for all 11 concepts. The results indicate that 1) considering the total transportation system is important, 2) expendable elements may be desirable and 3) evolutionary development can be a graceful and flexible part of all concepts. The system sketches for the other concepts are attached as Appendix 1.

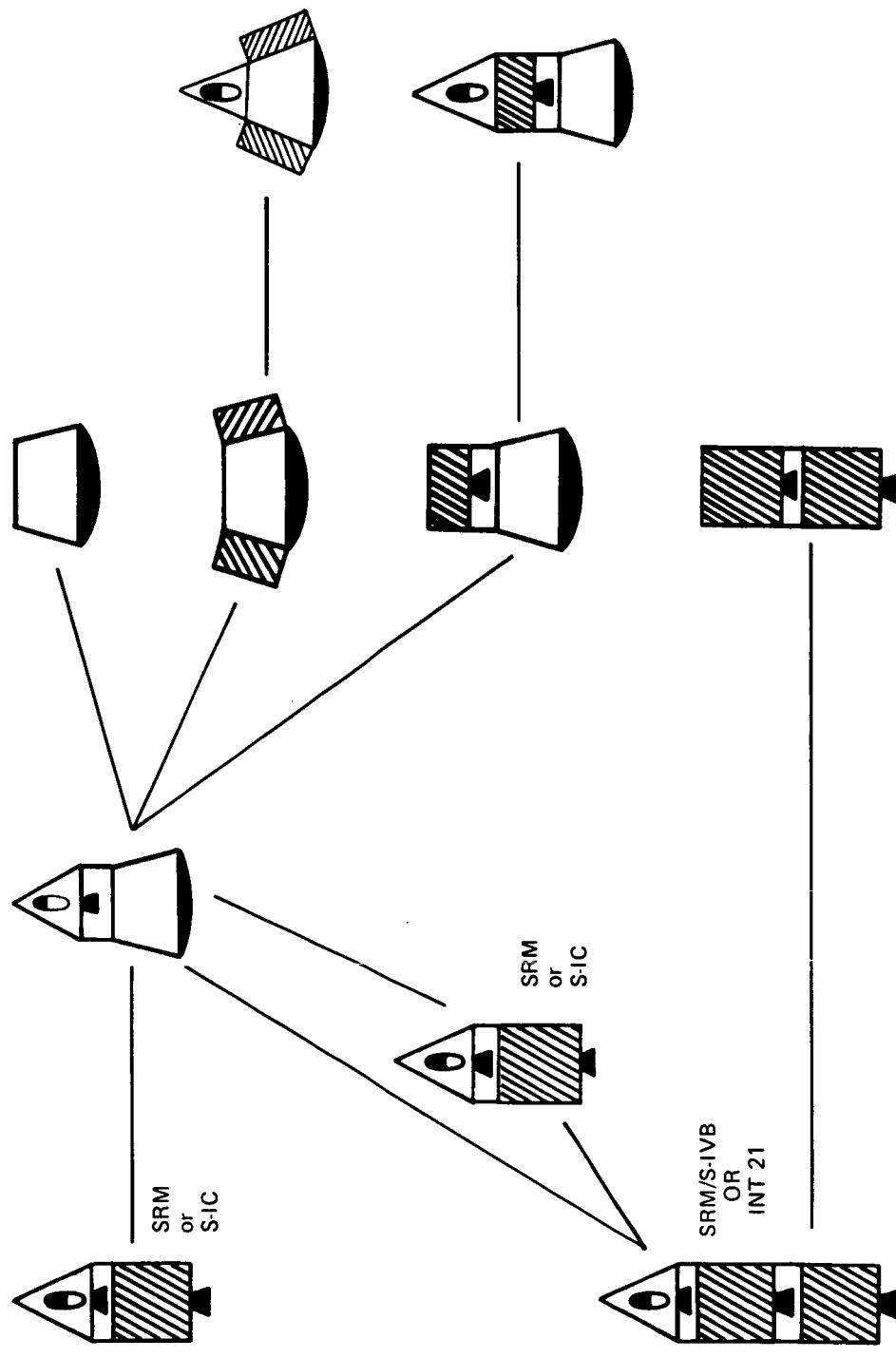
**TRANSPORTATION SYSTEMS
(CONCEPT 2)**

**COMPLEMENTARY
SYSTEMS**

**CREW/LOGISTICS
CONFIGURATION**

**CARGO
CONFIGURATION**

**CREW/LOGISTICS
ALTERNATIVES**



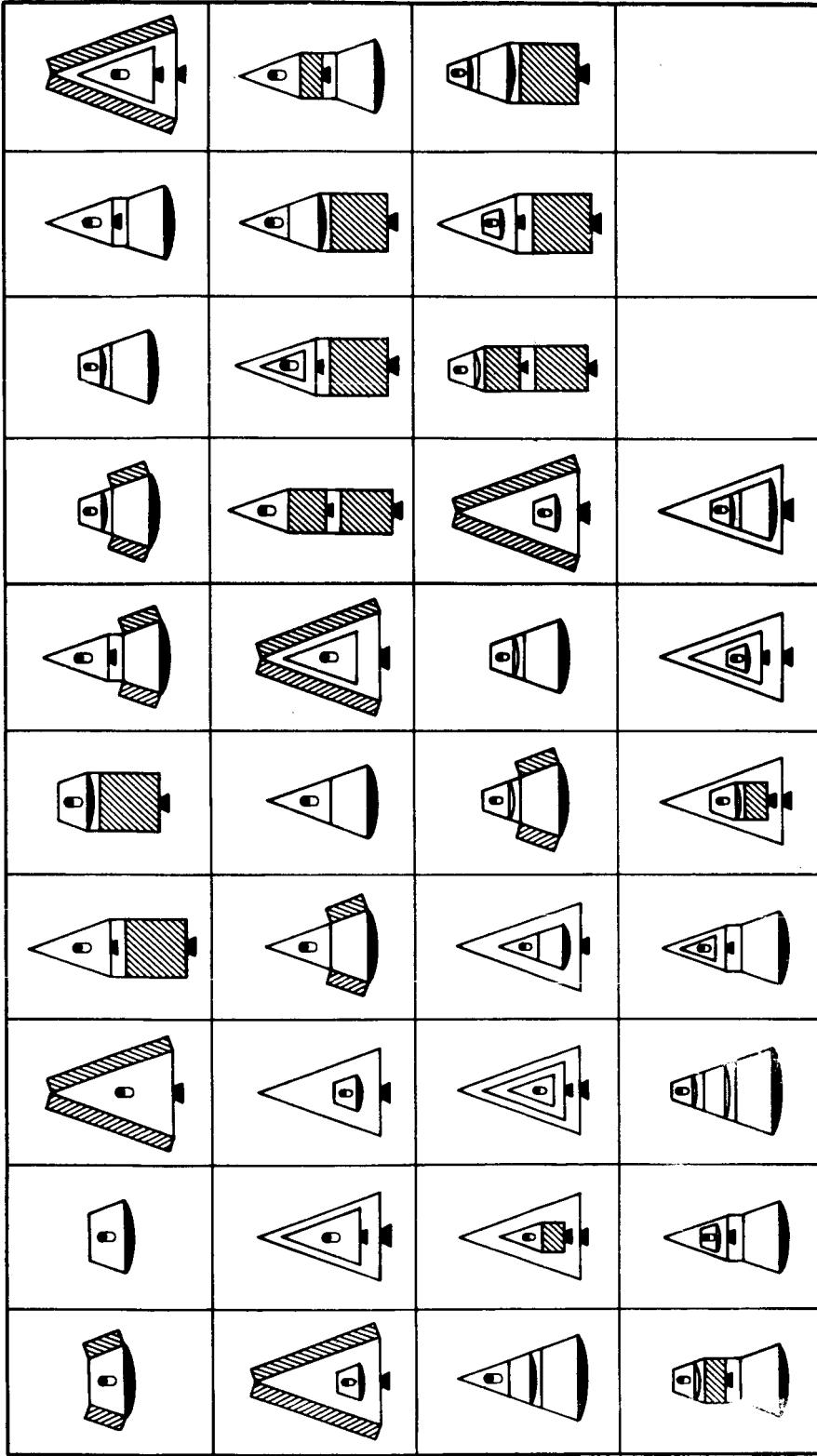
CREW VEHICLE CONCEPTS

The full complement of configurations that have passed the first level of screening are shown in cartoon fashion on the facing figure. They are arranged in order of their occurrence on the original alternative matrix.

Out of 60 original concepts, 37 seem to be technically or economically feasible. Most of these 37 show up as primary or secondary candidates in the transportation systems concepts presented in Appendix 1.

Expendable elements are indicated by cross-hatching, otherwise the code is the same as previously indicated. Unique cases of special interest occur when two identical booster stages are concerned; These will appear in Appendix 1, but are not indicated here.

CREW VEHICLE CONCEPTS



- SKETCH:
- MEANING:

• 0 CARGO
 • CREW
 • EXPENDABLE HARDWARE
 • OR
 • BOOST PROPULSION

▲ LIFTING BODY
 □ EXPENDABLE HARDWARE
 ◻ BALLISTIC BODY

RESULTS

It is clear that the total transportation system requirements must be considered in selecting candidate configuration concepts. Both the interim system possibilities and the cargo requirements impinge on the crew/logistics concepts. And the final selection must balance all these requirements.

From this first level analysis as many as 26 crew/logistics concepts seem attractive. Many of these concepts have similar cargo configuration concepts, reducing the total number of attractive cargo configurations to 13.

Many of these transportation concepts show advantages in one way or another over the current shuttle concept. Single stage to orbit systems offer operational simplicity; common launch vehicles for both the cargo and crew/logistics flights minimize the total number of developments and can support wide variations in future traffic distributions between cargo and crew/logistics missions.

The concept of an interim booster capable of lifting about 150,000 pounds fits very gracefully into most schemes for the total transportation system. It can help to minimize spending peaks by supporting sequential development of the shuttle elements. In addition it can temporarily (or perhaps even permanently depending on the economics) provide the large lifting capacity needed for cargo missions.

RESULTS

- CONSIDERATION OF TOTAL TRANSPORTATION SYSTEM REQUIREMENTS IS IMPORTANT IN EVOLVING SHUTTLE CONCEPTS.
- FEEDBACK FROM CARGO REQUIREMENT
- INTERIM SYSTEM
- MANY DIFFERENT GENERIC CONCEPTS SEEM PROMISING: 26 AS CREW/LOGISTICS CONFIGURATION CLASSES, AND 13 AS CARGO CONFIGURATION CLASSES.
- SEVERAL OF THESE CONCEPTS SHOW POTENTIAL FOR ADVANTAGES OVER THE CURRENT SHUTTLE CONCEPTS.
 - OPERATIONAL SIMPLICITY
 - FEWER DEVELOPMENTS
 - TRAFFIC ADAPTABILITY
- MANY CONCEPTS SHOW A VALUABLE ROLE FOR AN INTERIM BOOSTER IN THE 150K SIZE RANGE.
 - EVOLUTIONARY STEP
 - CARGO VEHICLE

APPENDIX

1

TRANSPORTATION SYSTEMS

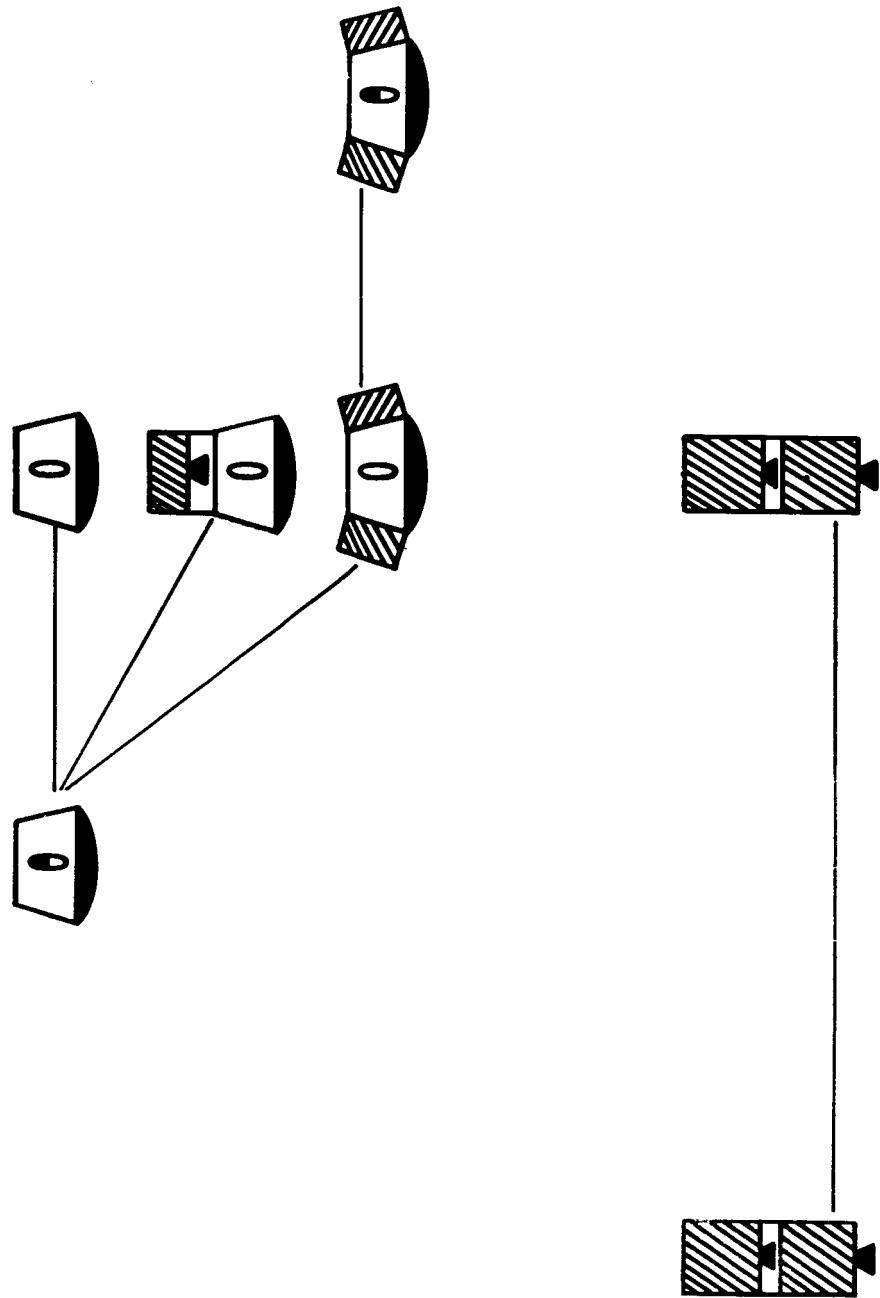
- 26 -

**TRANSPORTATION SYSTEMS
(CONCEPT 1)**

**COMPLEMENTARY
SYSTEMS**

**CREW/LOGISTICS
CONFIGURATION**

**CREW/LOGISTICS
ALTERNATIVES**

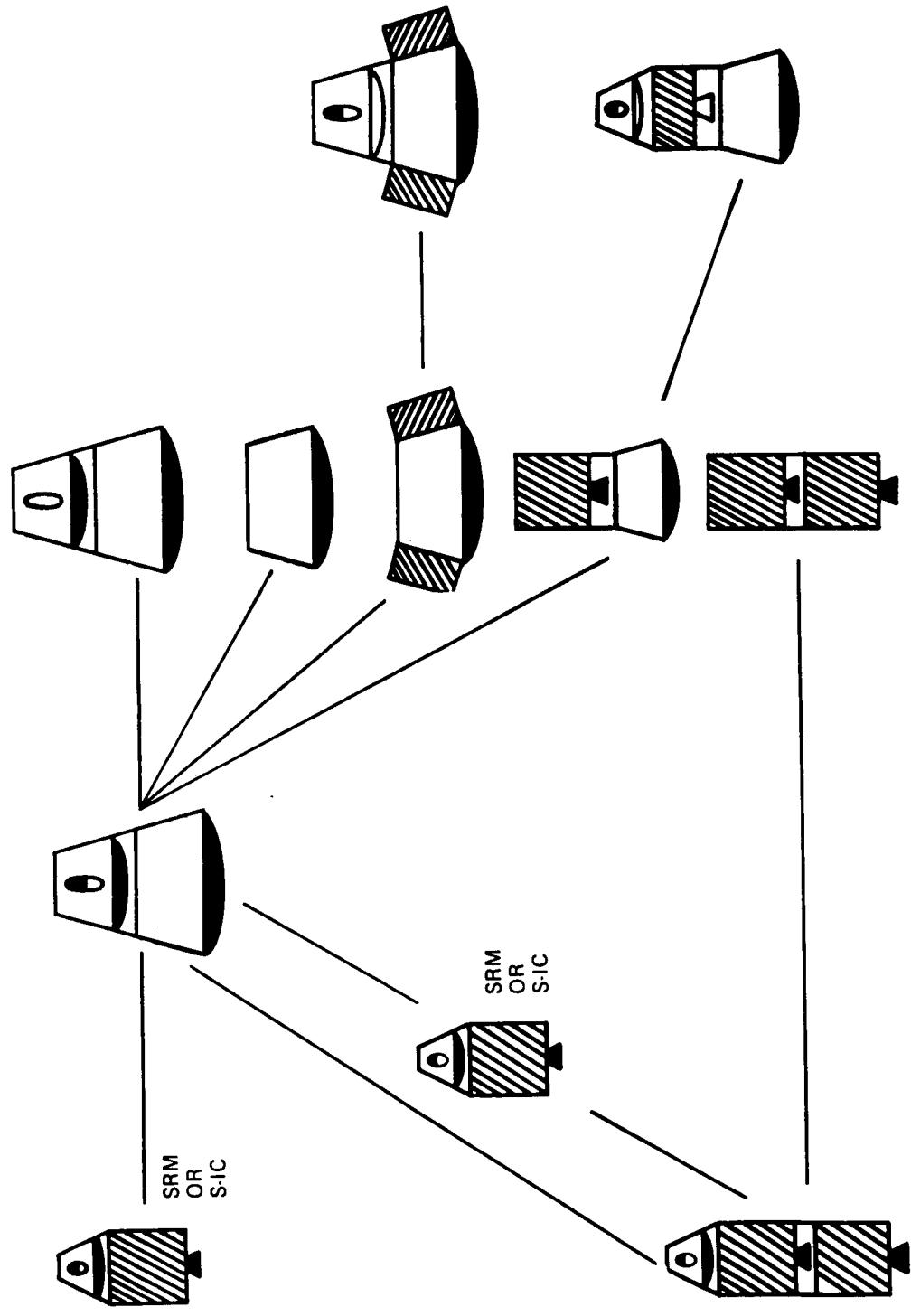


**TRANSPORTATION SYSTEMS
(CONCEPT 3)**

**COMPLEMENTARY
SYSTEMS**

**CREW/LOGISTICS
CONFIGURATION**

**CREW/LOGISTICS
ALTERNATIVES**

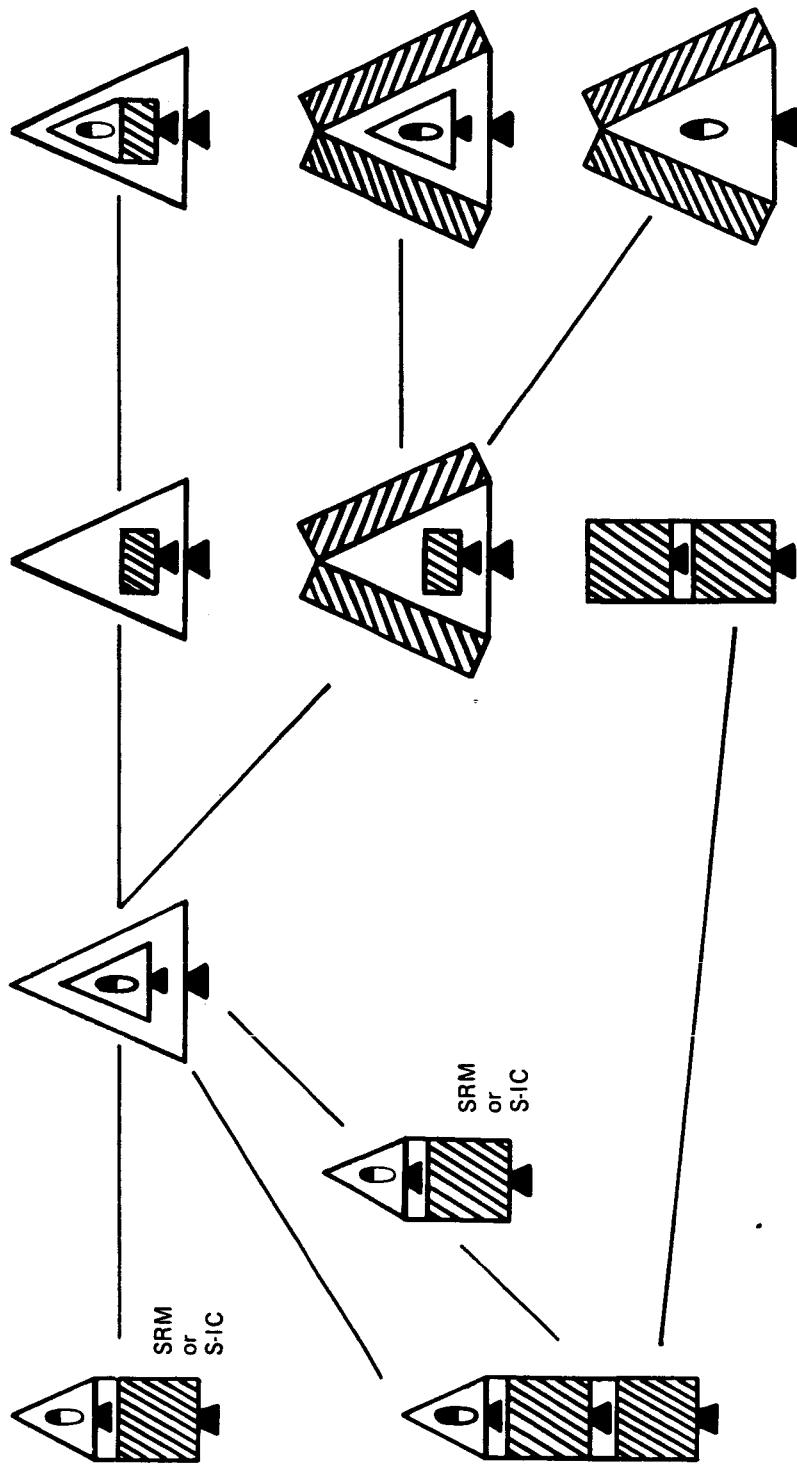


**TRANSPORTATION SYSTEMS
(CONCEPT 4)**

COMPLEMENTARY SYSTEMS
CREW/LOGISTICS CONFIGURATION

CREW/LOGISTICS ALTERNATIVES

CARGO CONFIGURATION



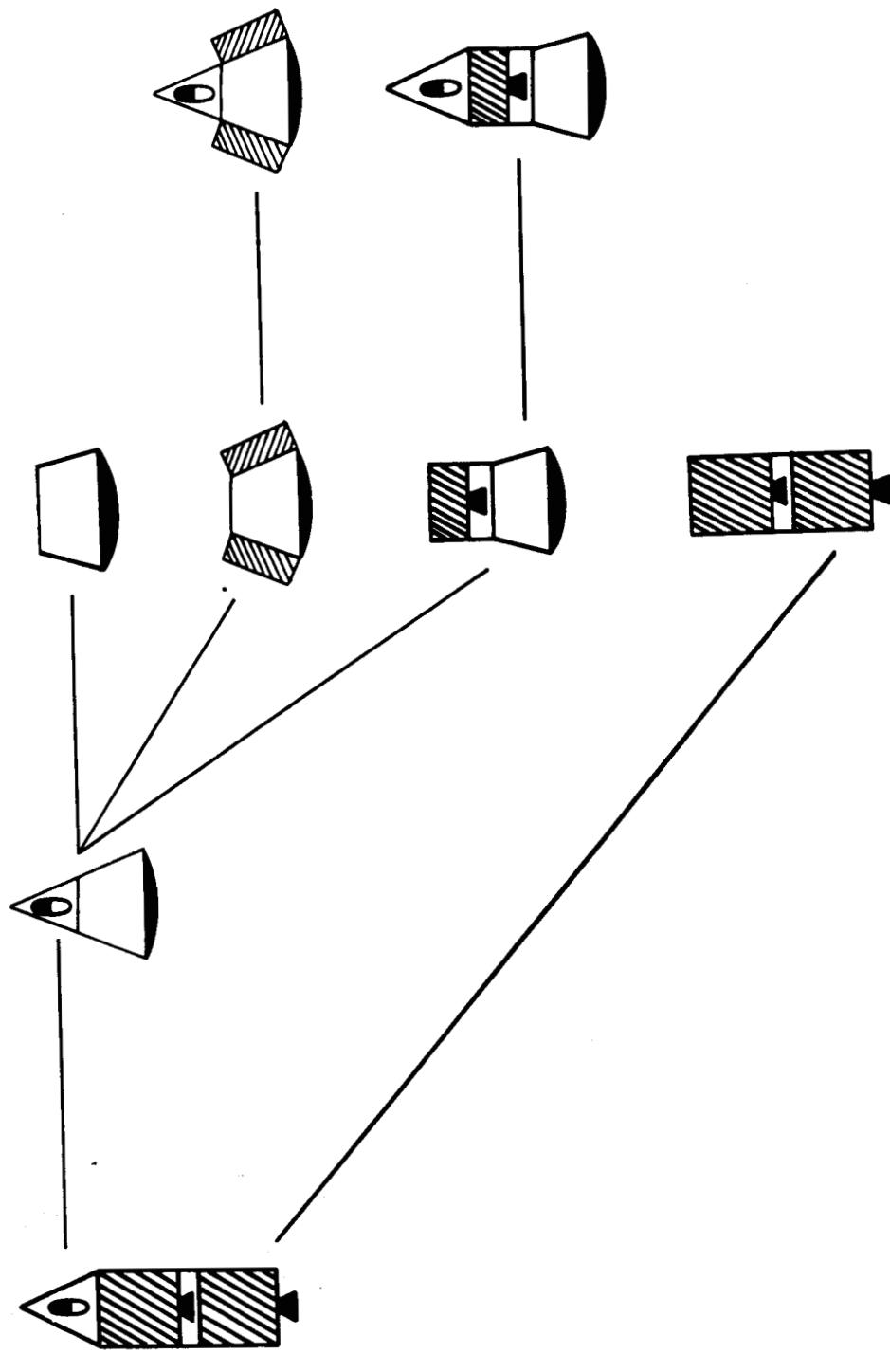
**TRANSPORTATION SYSTEMS
(CONCEPT 5)**

**CREW/LOGISTICS
CONFIGURATION**

**CARGO
CONFIGURATION**

**CREW/LOGISTICS
ALTERNATIVES**

**COMPLEMENTARY
SYSTEMS**

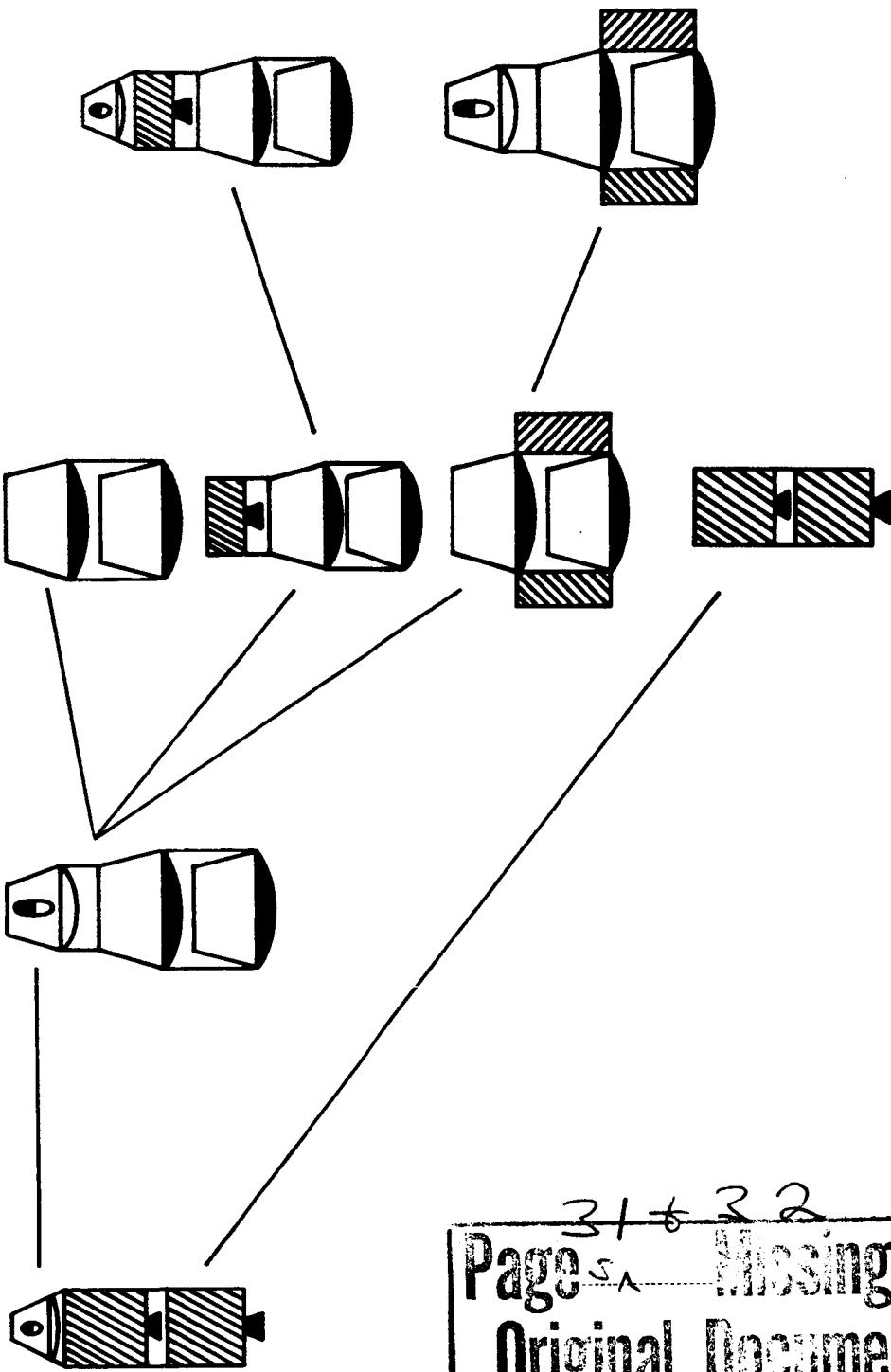


**TRANSPORTATION SYSTEMS
(CONCEPT 8)**

**COMPLEMENTARY
SYSTEMS**

**CARGO
CONFIGURATION**

**CREW/LOGISTICS
ALTERNATIVES**



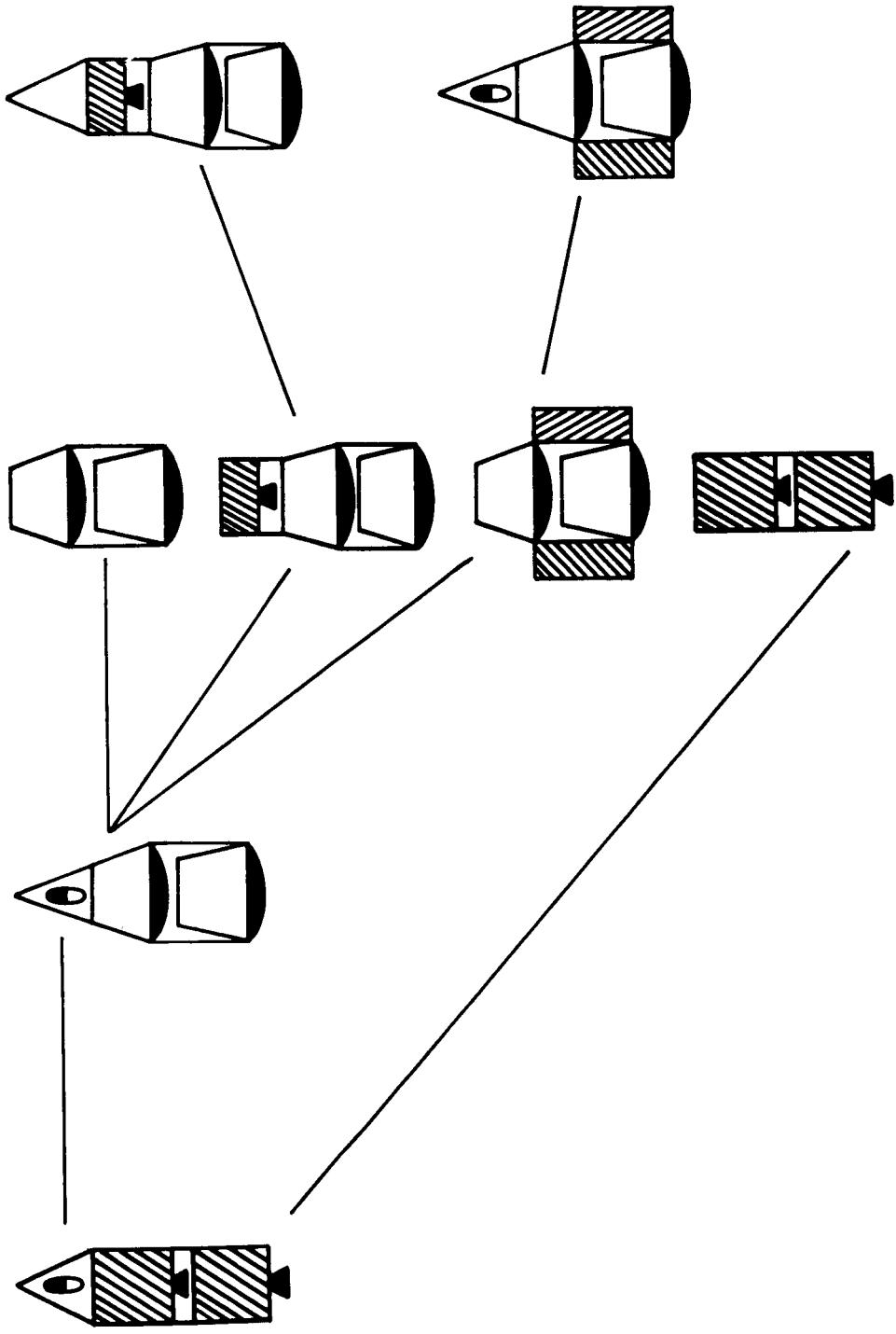
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**TRANSPORTATION SYSTEMS
(CONCEPT 9)**

**COMPLEMENTARY
SYSTEMS**

**CREW/LOGISTICS
CONFIGURATION**

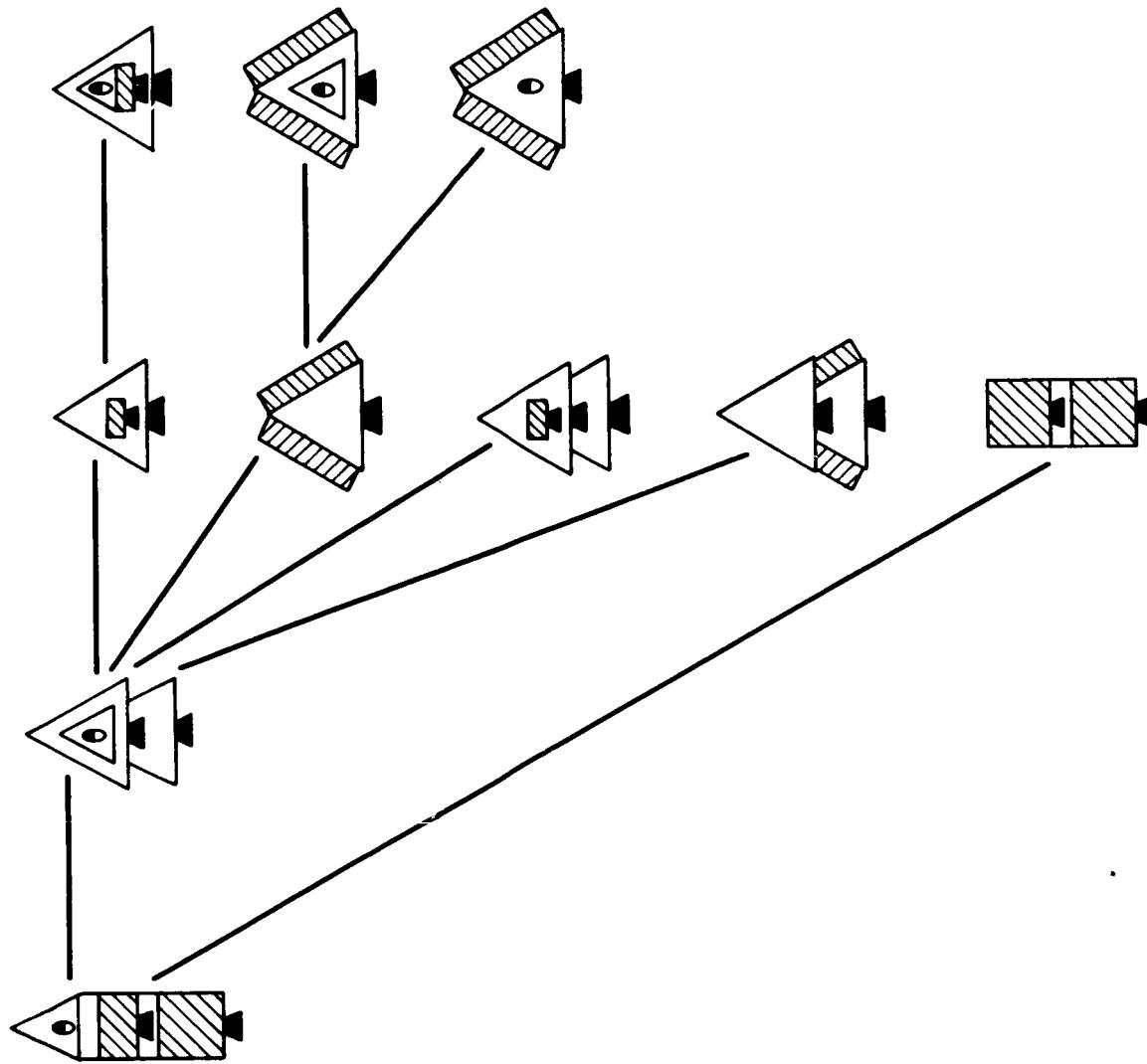
**CREW/LOGISTICS
ALTERNATIVES**



TRANSPORTATION SYSTEMS

CONCEPT 10

COMPLEMENTARY SYSTEMS CREW/LOGISTICS CONFIGURATION CARGO CONFIGURATION



TRANSPORTATION SYSTEMS
CONCEPT 11

COMPLEMENTARY SYSTEMS
CREW/LOGISTICS CONFIGURATION

CREW/LOGISTICS ALTERNATIVES

CARGO CONFIGURATION

